AERIs for ARM: Accuracy and Applications

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Introduction

Measurements from the atmospheric emitted radiance interferometer (AERI) are used within the Atmospheric Radiation Measurement (ARM) Program to improve our understanding of the atmospheric processes important for atmospheric radiation. One of the earliest ARM goals was the collection of high spectral resolution emission data for validation of radiative transfer model (RTM) calculations in the infrared (IR). Over the years, the list of applications of AERI data have grown to include remote sensing of atmospheric thermodynamic variables, atmospheric constituents, and surface properties. Fundamental to the success of these applications is the radiometric accuracy of the AERI IR atmospheric emission measurements. This paper presents the theoretical accuracy estimates of the AERI measurements and demonstrated performance derived from data collected in the laboratory and in the field.

Accuracy

The accuracy of AERI radiance measurements can be estimated through a perturbation analysis of the calibration equation given below (Revercomb et al. 1988; Knuteson et al. 1999).

$$N = (B_H - B_A)\,\mathrm{Re}\left(\frac{C_S - C_A}{C_H - C_A}\right) + B_A \tag{1}$$

where N is the calibrated radiance spectrum, B_H is the effective Planck emission for the hot blackbody, B_A is the effective Planck emission for the ambient blackbody, C_S is the complex spectrum for the sky view, C_H is the complex spectrum for the hot blackbody view, C_A is the complex spectrum for the ambient blackbody view, and Re() is the real part of the complex ratio. The complex spectra are simply the Fourier transform of the observed interferogram. In the AERI systems for ARM, the instrument measures 90 complex spectra in a 3.5-minute dwell period during the zenith sky view and 45 complex spectra in 100 seconds during each of the hot and ambient reference blackbody dwell periods. The hot reference is typically controlled to +60°C while the ambient reference is unheated and floats close to the outside ambient temperature.

The design goal of the AERI systems is an absolute accuracy of 1% of ambient temperature Planck radiance (or better). Figure 1 shows the uncertainty in AERI calibration derived by perturbing each of the variables in Eq. (1) in turn. The result is presented both as a root sum square of the individual error components and as a "worst case" sum of the absolute values of each error term (sumABS).

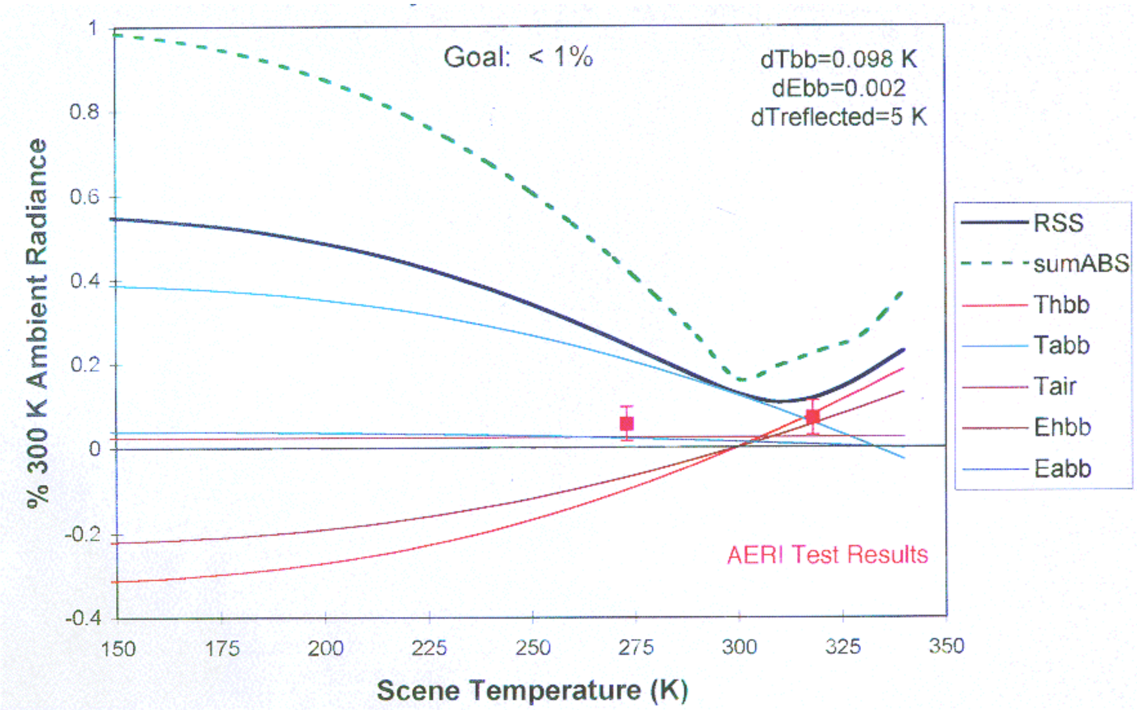

Figure 1. Theoretical accuracy estimates of the AERI radiance measurement at 770 cm^{-1} as derived from uncertainty estimates of the variables in the calibration equation compared to actual AERI performance in laboratory tests.

The ability of the AERI to meet this challenging accuracy goal has been accomplished by using well characterized blackbodies integrated into the instrument as calibration references and viewing these references often. The blackbodies used by the AERI system for ARM were designed and built at the University of Wisconsin Space Science and Engineering Center (UW-SSEC) specifically for the AERI project. Figure 2 shows the UW-SSEC blackbody design and implementation used for the AERIs for ARM.

The AERI blackbodies use a cavity approach, which provides high emissivity that can be well characterized. The thick-walled aluminum cavity is easy to machine and provides excellent heat conduction, leading to low thermal gradients. The inner surface of the cavity is painted with Chemglaze Z306, which provides a hardy, diffuse, and stable surface that has a high emissivity in the IR. A diffuse surface was chosen over a specular one in order to minimize the impact of slight contamination (dust) on the overall cavity emissivity. The temperature sensors used by the AERI blackbody are YSI 46041 Super Stable thermistors. The advertised stability of these sensors is 0.01 K after 100 months at 70 K.

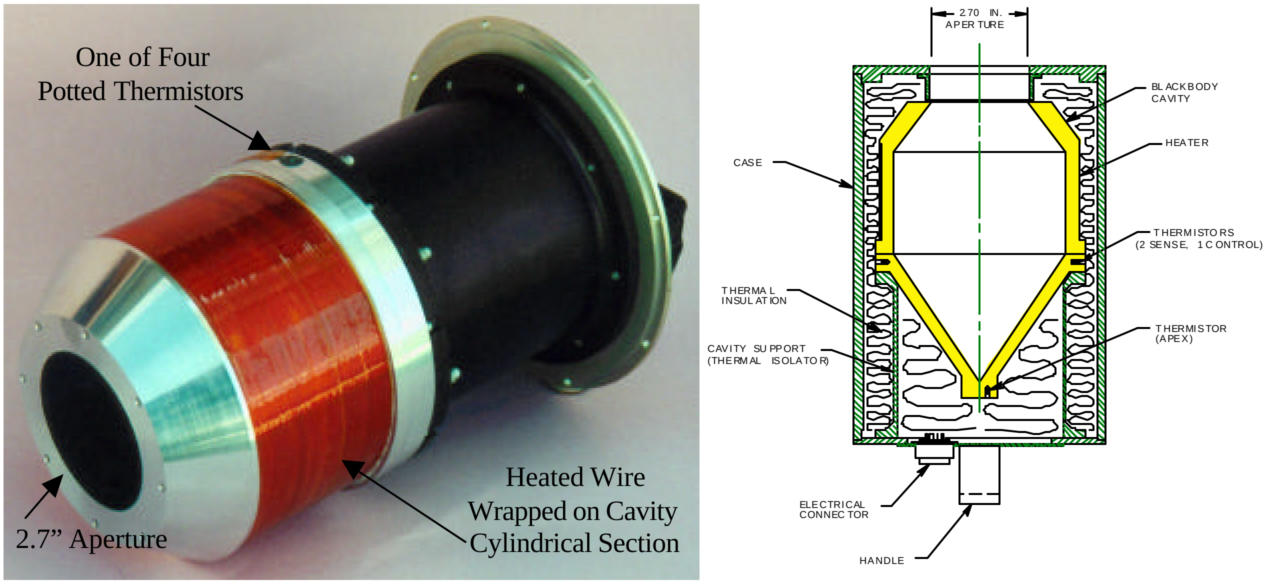

Figure 2. AERI blackbodies used as on board calibration references for ARM.

In addition to their stability, these sensors are attractive because they are easily coupled, thermally, to the complicated cavity structure and they are reasonably rugged. The thermistor calibration is well characterized with three coefficients that are obtained at three different calibration points spanning the desired temperature range.

The uncertainty in knowledge of the temperature and emissivity of the AERI blackbodies is given in Table 1 for both a root sum square and an absolute summation of the individual error components. Laboratory tests of the calibration performance have been performed on each AERI system prior to delivery and will be repeated periodically. Figure 3 shows the result of one such test using an intermediate temperature (45°C) blackbody reference in the sky view and a blackbody submerged in an ice bath in the down view.

Table 1. AERI blackbody uncertainties.

Error Estimate	Root Sum Square	Absolute Sum
Temperature	0.057°C	0.098°C
Emissivity	0.0012	0.002

The laboratory performance illustrated in Figure 3 can be compared against the theoretical uncertainty estimate derived from Eq. (1). The error between the measured temperature at 770 cm^{-1} for a 45°C and 0°C lab test is shown in Figure 1. The measured performance in the laboratory is well within the limits of the theoretical uncertainty estimate, which is consistent with the expectation that the actual uncertainty for an individual instrument will be much better than the worst case estimate.

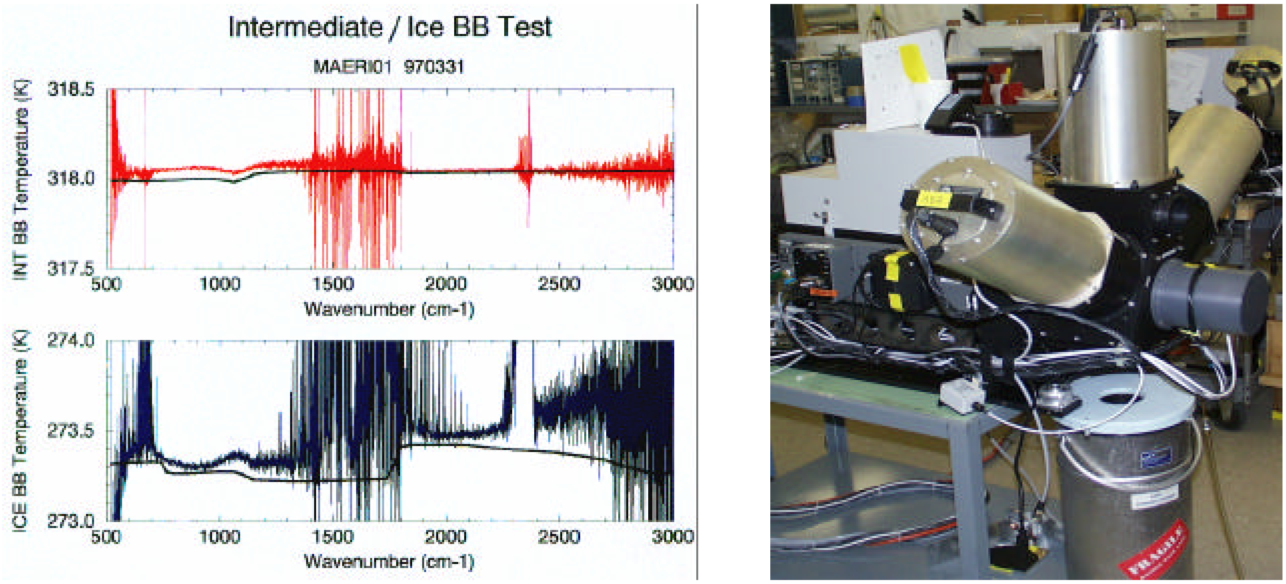

Figure 3. Laboratory tests of the calibration performance of an AERI instrument.

In June of 1997, the AERI-01 hot and ambient blackbodies were replaced with new units and the originally installed blackbodies were re-calibrated using the dedicated AERI facilities at the University of Wisconsin. Figure 4 illustrates that over the 30-month period from initial blackbody calibration to the re-calibration (December 1994 to June 1997), there was less than 0.05°C drift in the cavity temperature-sensing thermistors. At the time of blackbody change-out, additional testing was performed on the AERI-01 instrument that showed the thermistor resistance readout electronics drift (when converted to equivalent temperature) was on the order of ± 0.005°C. The June testing provided us the first demonstration of the excellent long-term stability of the AERI blackbody thermistors and readout electronics.

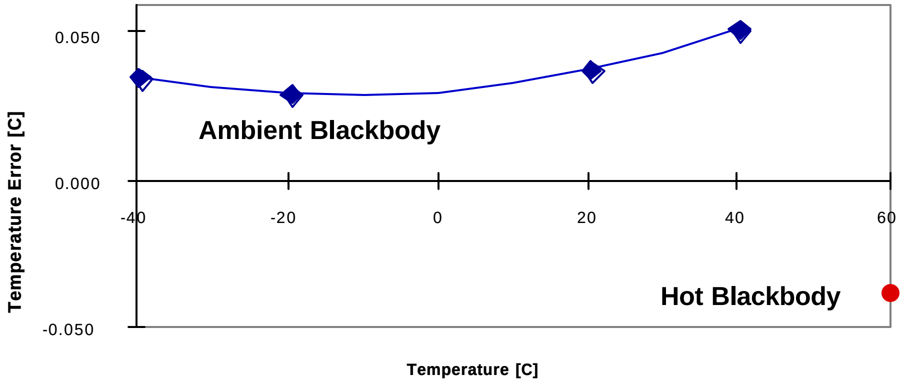

Figure 4. AERI-01 blackbody thermistor drift over the 30-month period from December 1994 to June 1997. Over the temperature operating range of the ambient blackbody (-40 to +40°C) and at the hot blackbody operating temperature of +60°C, the drift was less than 0.05°C. The thermistor resistance readout electronics drift converted to equivalent temperature error was measured to be an order of magnitude smaller than the thermistor drift shown above.

We continue to monitor the blackbody temperature measurement stability of all the AERI blackbodies in order to better characterize long-term behavior. An important goal for monitoring blackbody stability is to define the maximum allowable time between calibrations; this period is now estimated to be on the order of 30 months.

In-the-field comparisons of AERI systems have been made routinely at the ARM Southern Great Plains (SGP) site over the past several years. Figure 5 shows the level of agreement that is typically found between two AERI systems when viewing the same column of atmosphere during the same time period.

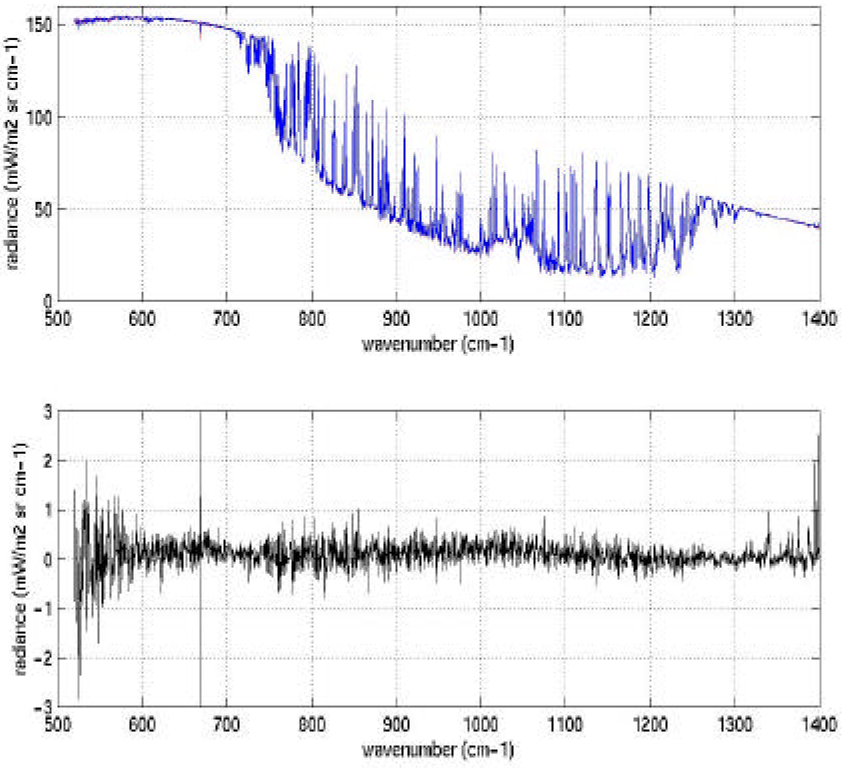

Figure 5. Comparison of two downwelling radiance observations from two different AERI systems from a field intercomparison performed at the SGP central facility on September 16, 1997, between 04:00 Universal Time Coordinates (UTC) and 05:00 UTC. The upper panel is an overlay of the two observations (AERI-01 in blue and AERI-00 in red) averaged over a one-hour period. The lower panel is the radiance difference (AERI-01 minus AERI-00). Note that one percent of ambient radiance is about 1 mW/(m^2 sr cm^{-1}) at 1000 cm^{-1} so the AERI-01/AERI-00 radiance difference is within the AERI accuracy estimate.

Applications

The applications of AERI measurements cover a broad range of topics related to the atmospheric temperature, radiatively important atmospheric constituents, and the earth's surface. A list of applications of AERI measurements is given below with reference to publications that provide more detailed information:

- planetary boundary layer temperature and water vapor retrievals (Feltz et al. 1999; Feltz et al. 2000; Schmit et al. 2000; Smith et al. 1999; Turner et al. 2000)
- sea surface temperature and emissivity (Smith et al. 1996; Minnett et al. 2000; Wu and Smith 1997)
- land surface emissivity (Bower et al. 1999)
- cloud radiative properties (Collard et al. 1995; DeSlover et al. 1998; DeSlover et al. 1999)
- carbon monoxide and ozone retrievals (McMillin 1997)
- line-by-line atmospheric radiative transfer model validation (Clough et al. 1997; Tobin et al. 1999; Knuteson et al. 1998; Revercomb et al. 1990).

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